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The Relationship of MSS and TM Digital Data with Suspended Sediments, Chlorophyll, and Temperature in Moon Lake, Mississippi

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A comparison of six concurrent Landsat MSS and TM scenes was made to determine the relationship of Landsat digital data with suspended sediments, chlorophyll, and temperature in the surface water of an agricultural lake. There were no significant differences in best correlations between MSS or TM data with surface suspended sediments. Thus, the advantage of using MSS is the ability to monitor large areas with significantly less data. TM data can be efficiently used to monitor smaller lakes and reservoirs. TM Band 1 reflectance was the only Landsat data that accounted for at least 50% of the variability in the chlorophyll data. This would not be adequate for a monitoring program for chlorophyll in sediment dominated lakes, such as Moon Lake. TM thermal data were highly correlated with surface water temperature. TM measured surface water temperatures could be useful in determining water balance in small agricultural reservoirs. A monitoring program based on Landsat MSS and TM scanners can provide data on suspended sediments that would allow the location of reservoirs with significant suspended sediment and allow better conservation assessment and planning.

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INTRODUCTION

The quality of surface water in streams, lakes, and reservoirs is a major concern around the world. Off-site downstream damage to water quality has been estimated to cost $6–7 billion per year in the United States (Ribaudo et al., 1989; Scaling, 1987). Major factors affecting surface water quality are suspended sediments, chlorophyll, nutrients, and pesticides. Current technology to measure these indicators of water quality involves *in situ* measurements or collection of water samples for subsequent laboratory measurements. Although this technology gives accurate measurements for a point in time and space, it is expensive, time-consuming, and, more importantly, does not give either the spatial or temporal view of water quality that is needed for accurate assessment and monitoring of surface water quality problems in an individual lake or in multiple lakes across the landscape.

A technique is needed for monitoring changes in surface water quality parameters to provide a rapid assessment of both spatial and temporal variability in surface water quality. Remote sensing techniques have been used in many applications to provide spatial and temporal data about landscape features. Satellite remote sensing techniques also provide a cost effective method for monitoring large segments of the landscape.

Two of the major factors affecting surface water quality, suspended sediments and chlorophyll, produce visible changes in surface waters and reflected solar radiation. Such changes in the spectral signal from surface water should be measurable with satellite multispectral scanner data. Satellite sensors have been studied for measuring changes in surface water radiance and reflectance as it is related to suspended sediments and chlorophylls in surface water (Carpenter and Carpenter, 1983; Harrington et al., 1989; Lathrop and Lillesand, 1986; Lindell et al., 1986; Lyons et al., 1988; Ritchie et al., 1987; 1989; Ritchie and Cooper, 1988; Schiebe et al., 1988; Verdin, 1985). These studies have shown that multispectral data can be used for detecting spatial and temporal variations in surface suspended sediments. The application of a technique using satellite multispectral measurements of surface water quality will make it possible to monitor the landscape effectively and efficiently to locate water bodies with significant surface water quality problems. Such a technique would provide valuable data for conservation assessments and for developing plans to reduce the movement of eroded soils and other pollutants from watersheds. Conservation planning could be concentrated on watersheds of those lakes and reservoirs with the most serious water quality problems.

Most studies of surface water quality with Landsat data have been made using either Multispectral Scanner (MSS) or Thematic Mapper (TM) data. TM sensor provides higher spatial and spectral resolution than MSS. The purpose of this paper is to compare Landsat MSS and TM data for six dates on the same lake for determining suspended sediments and chlorophyll in surface water to determine which sensor provides the best data for monitoring surface water quality.

METHODS

The study area was Moon Lake, an oxbow lake located next to the Mississippi River levee in the northwestern part of Mississippi (Ritchie et al., 1987). Moon Lake is approximately 12 km long and 1 km wide and has a watershed area of 166 km^2. Land use on the watershed is predominantly agriculture, with soybeans and cotton being the major crops. The soils have developed on Mississippi River alluvial flood plain deposits. Little channel modification has occurred in the watershed leaving most streams with a wetland riparian zone along the stream channels. Surface soil erosion on the uplands has led to water quality and sedimentation problems in the lake. Previous studies on surface suspended sediments in this lake have been made using Landsat MSS data (Ritchie et al., 1987; 1989; Ritchie and Cooper, 1987; 1988)

Biweekly measurements of water quality parameters were made at five locations in the lake between June 1982 and June 1985. At each lake site, *in situ* measurements were made of the surface to lake bottom profile of water temperature. Also at each sample site, two water samples of approximately 1 L were collected from the surface 5 cm of the lake. These samples were sealed and transported to a laboratory.

For each water sample, total solids were measured by evaporating a 100 mL aliquot to dryness and weighing the residue. Dissolved solids were measured by filtering a 100 mL aliquot through a 0.45 μm filter, evaporating the filtrate to dryness, and weighing the residue. Suspended sediments (suspended solids) were calculated as the difference between total solids and dissolved solids. For each water sample, chlorophylls were measured by extraction with acetone and measuring the extracted chlorophyll with a colorimeter (APHA, 1975).

Geometrically corrected (Verdin, 1983) digital Landsat data (Path 23 Row 36) for both MSS and TM were purchased for each of six cloud-free days when TM data were available between June 1982 and June 1985. These were the only six dates that TM data were available. Field data measured during the biweekly sampling were used to compare with the Landsat data. For Landsat MSS, the data covered a 256×240 pixel area (383 km^2) surrounding the lake. For TM, the data analyzed covered a 512×400 pixel area (184 km^2) surrounding the lake. All extractions and analyses of digital data were made using a personal-computer-based image processing system.

The minimum pixel value for the four spectral bands for the 256×240 MSS pixel area and the seven TM bands for a 512×400 pixel area from the TM scenes was determined for each of the six scenes. Digital data for four MSS bands and seven TM bands were extracted for a 5×5 pixel array centered around each field sample site (Ritchie and Cooper, 1987). A 13×13 pixel array was also extracted around each sample site from TM scenes. A paired *t*-test showed that the difference between the average pixel values for 5×5 and 13×13 TM pixel arrays was not significantly different from zero at a 30% or greater level of probability. Therefore, data from 5×5 TM pixel arrays were compared with 5×5 MSS pixel array data in this paper, although it covered a seventh of the area of 5×5 MSS pixel arrays. A 5×5 pixel array was the largest MSS pixel array that could be extracted without interference from shallow water (bottom reflectance) or shoreline pixels. If 5×5 or smaller pixel arrays could be used, then Landsat data could be used to monitor small farm ponds, thus increasing the usefulness of satellite monitoring techniques for conservation assessment programs.

Two data sets were derived from extracted digital data and used for analyses. The first data set was based on the average value of the 25 digital values extracted from the 5×5 pixel arrays from the MSS and TM scenes with no corrections. This data set will be referred to as raw pixel data in this paper. In the second data set, average digital values were corrected by subtracting the minimum pixel value in each scene from the average digital value for each 5×5 pixel array. This technique, often called the dark pixel correction method, has been suggested as a method to correct for differences in atmospheric transmission between different dates of Landsat data (Rochon and Langham, 1974). This data set will be referred to as the dark pixel corrected data in this paper.

To compare Landsat MSS and TM data collected on different dates, average raw pixel and dark pixel corrected data were converted to physical values (Robinove, 1982) of radiance ($\mathrm{mW\ cm^{-2}\ sr^{-1}\ \mu m^{-1}}$). Standard calibration data (Markham and Barker, 1986; Price, 1987) for each satellite, sensor, and band were used for this calculation. Reflectance values for MSS and TM data were computed based on these calculated radiance data, sun angle, and exoatmospheric spectral irradiance (Markham and Barker, 1986). Surface water temperature was calculated from Landsat TM Band 6 average raw pixel data using the sensor calibration data and equations (Markham and Barker, 1986).

With five sample sites on six different dates, each data set had 30 date values for MSS, TM, and field measurements. These values were used to determine statistical relationships between radiance and reflectance for different MSS and TM bands and field measurements (suspended sediments, total chlorophyll, chlorophyll-a, and temperature) and for the relationship between radiance and reflectance measurements of MSS and TM sensors.

RESULTS AND DISCUSSION

Field measurements of suspended sediment concentration for the date (Table 1) nearest a satellite overpass had a range of 37–196 $\mathrm{mg\,L^{-1}}$. The maximum value (196 $\mathrm{mg\,L^{-1}}$) is lower than the maximum (410 $\mathrm{mg\,L^{-1}}$) measured during the June 1982 to June 1985 field data collection (Ritchie et al., 1989). The range for the concentration of chlorophyll-a and total chlorophyll also provides a good distribution and range for analyses.

Field data collection was within 2–5 days of the Landsat date on four of the dates used (Table 2). Since on four of the sample dates there was no significant precipitation or other weather change, the field data collected and used for the six dates of Landsat data represents the water quality in the lake. On the other two dates, there was precipitation. However, there were no indications of significant inflow of suspended sediments between the date of Landsat overpass and the date of the field measurement since those dates had the lowest and third lowest suspended sediments measured and suspended sediments were the same or less than that measured 2 weeks earlier. The precipitation that came between 26 January and 13 February 1985 included approximately 10 cm of snow and prevented field data collection on 26 January 1985. Differences between the minimum and maximum temperatures on the day of Landsat

Table 1. Summary of the Field Data Used To Compare with the Six Landsat MSS and TM Scenes (Total Number of Samples = 30)

		Mean	*Minimum*	*Maximum*
Suspended sediments	($\mathrm{mg\,L^{-1}}$)	99.4	37	196
Chlorophyll-a	($\mathrm{mg\,m^{-3}}$)	8.47	1.87	43.29
Total chlorophyll	($\mathrm{mg\,m^{-3}}$)	14.12	4.61	56.15
Water temperature	(°C)	16.99	2.98	30.54

overpass and the average minimum and maximum temperature between the date of the Landsat overpass and field data collection were not large. There are no indications of a significant change in weather patterns from weather data available from the two nearest weather stations (Helena, Arkansas and Clarksdale, Mississippi) that would have caused significant changes in water quality parameters measured between the date of the Landsat overpass and the field data collection. Although suspended sediments, chlorophyll and temperature may change rapidly, there is no indication in our 3-year data set or the weather pattern that there was a significant change in water quality between the date of the field collection of data and the date of the six Landsat scenes used for these analyses. Therefore, actual field measurements were used for our analyses rather than attempting to estimate field measurements for the date of each Landsat overpass.

A comparison of radiance values calculated from MSS and TM Bands 1–4 digital data shows that bands measuring similar wavelengths gave similar radiance values. TM bands with narrower spectral bands than MSS bands measured less radiance in each comparable band as expected. Linear regression analyses produced high correlation coefficients (r) for all comparisons (Table 3) between similar bands of MSS and TM data with the best correlations ($r = 0.99$) between TM Band 2 and MSS Band 1, TM Band 3 and MSS Band 2, and TM Band 4 and MSS Band 3 or 4 for radiance measurements calculated from raw pixel data.

Comparisons of radiance calculated from raw pixel data from MSS and TM data gave higher correlation coefficients than radiance calculated from dark pixel corrected data. This difference may be because the minimum pixel value for the MSS scene was selected from a ground area that was approximately two times larger than that of

Table 2. Dates of Landsat Scenes and Field Data and Weather Conditions[a]

MSS and TM Date	Field Data Date	Total[b] Precipitation (mm)	Temperature[c] (°C) Date Min	Date Max	Average Min	Average Max
13 Jan 83	11 Jan 83	0.0	−4	5	−3	11
18 Jul 84	10 Jul 84	2.3	21	34	22	34
26 Jan 85	13 Feb 85	94.5	−9	11	−7	3
15 Mar 85	19 Mar 85	0.0	5	14	6	17
18 May 85	16 May 85	0.0	10	22	14	26
3 Jun 85	29 May 85	21.5	23	36	19	31

[a] Weather data are for Helena, Arkansas weather station which is approximately 20 k northwest of Moon Lake.
[b] Total precipitation for the period between the date of Landsat overpass and field data collection.
[c] Temperature is given for the "Date" of the Landsat overpass and for the "Average" temperature for the period between the date of Landsat overpass and field data collection.

Table 3. Correlation Coefficients (r) for a Linear Relationship between Landsat MSS and TM Radiance (Bandwidth in μm)

TM Radiance		MSS Radiance Band 1 (.5–.6)	Band 2 (.6–.7)	Band 3 (.7–.8)	Band 4 (.8–1.1)
		Calculated from Raw Pixel Data			
Band 1	.45–.52	0.99	0.99	0.94	0.90
Band 2	.52–.60	0.99	0.99	0.94	0.88
Band 3	.63–.69	0.97	0.99	0.98	0.92
Band 4	.76–.90	0.89	0.93	0.99	0.99
		Calculated from Dark Pixel Corrected Data			
Band 1	.45–.52	0.87	0.98	0.93	0.91
Band 2	.52–.60	0.97	0.92	0.90	0.90
Band 3	.63–.69	0.87	0.97	0.98	0.87
Band 4	.76–.90	0.83	0.81	0.91	0.83

Table 4. Correlation Coefficients (r) for a Linear Relationship between Landsat MSS and TM Reflectance (Bandwidth in μm)

TM Reflectance		*MSS Reflectance* Band 1 (.5–.6)	Band 2 (.6–.7)	Band 3 (.7–.8)	Band 4 (.8–1.1)
	Calculated from Raw Pixel Data				
Band 1	.45–.52	0.01	−0.06	0.09	0.27
Band 2	.52–.60	0.53	0.50	0.50	0.59
Band 3	.63–.69	0.35	0.63	0.76	0.79
Band 4	.76–.90	0.53	0.82	0.97	0.97
	Calculated from Dark Pixel Corrected Data				
Band 1	.45–.52	0.09	0.52	0.37	0.50
Band 2	.52–.60	0.96	0.24	0.56	0.62
Band 3	.63–.69	0.31	0.83	0.83	0.50
Band 4	.76–.90	0.69	0.63	0.88	0.83

the TM scene. This difference in size used to locate the minimum pixel on the two scenes may have resulted in a different area of the MSS and TM scenes being used in the dark pixel correction technique, thus causing a difference in the dark pixel corrected data for the MSS and TM on the same date.

A similar comparison of reflectance values calculated for MSS and TM Bands 1–4 data found that comparable bands of MSS and TM gave similar reflectance values. Linear regression analyses found significant correlation coefficients (r) for comparable bands (Table 4). Regression coefficients were lower than comparable coefficients for radiance and usually accounted for less than 80% of the variability.

These comparisons between the Landsat MSS and TM radiance and reflectance measurements suggest that TM Bands 2, 3, and 4 paired with MSS Bands 1, 2, and 4 provided similar data on the spectral properties of the surface water of Moon Lake for the six scenes compared. If MSS and TM in these three bands are providing similar data on the spectral properties of surface water, then can similar determinations of water quality parameters be made from either MSS or TM sensor data?

Several models were used to examine the relationship between surface suspended sediments and MSS or TM radiance and reflectance data. These models included linear, exponential, and log transformations (Schiebe et al., 1988). Radiance and reflectance for all bands and all band combinations and band ratios based on digital numbers were used in these models. A simple linear model was found to best fit the MSS and TM radiance and reflectance data for these six dates. The linear regression had a form of

$$R = A + B * C, \tag{1}$$

where R is MSS or TM radiance or reflectance, A and B are the intercept and slope calculated from data, and C is the concentration of suspended sediments. Band combinations or band ratios based on the digital data did not provide any higher correlation coefficients with any of the different models used for this data set than the radiance or reflectance data.

A linear model was expected to provide a strong relationship between surface suspended sediments and MSS or TM data since the maximum concentration of surface suspended sediments was less than 200 $\mathrm{mg\,L^{-1}}$ in this data set. At concentrations of suspended sediments less than 200 $\mathrm{mg\,L^{-1}}$, several laboratory and field studies have shown linear increases in radiance or reflectance with increasing surface suspended sediments (Ritchie et al. 1976; Holyer 1978; Whitlock et al., 1981) at wavelengths between 0.6 μm and 0.9 μm. At concentrations of suspended sediments greater than 200 $\mathrm{mg\,L^{-1}}$, radiance and reflectance from surface water tend to saturate making a nonlinear model better fit the data (Ritchie et al., 1989).

The correlation coefficients (r) for the linear models show that the relationship between suspended sediments and reflectance usually had higher correlation coefficients than suspended sediments and radiance for either MSS or TM data

Table 5. Correlation Coefficients (r) for a Linear Relationship between Suspended Sediments and Radiance or Reflectance Calculated from Landsat MSS and TM Sensor Data

	Band 1	*Band 2*	*Band 3*	*Band 4*
	Calculated from Raw Pixel Data			
MSS radiance	0.25	0.34	0.52	0.59
MSS reflectance	0.38	0.71	0.88	0.86
TM radiance	0.28	0.27	0.38	0.59
TM reflectance	0.14	0.33	0.68	0.88
	Calculated from Dark Pixel Corrected Data			
MSS radiance	0.50	0.33	0.38	0.59
MSS reflectance	0.38	0.61	0.58	0.86
TM radiance	0.27	0.39	0.33	0.59
TM reflectance	0.35	0.32	0.49	0.73

(Table 5). There was little difference in the correlation coefficients for the relationship between suspended sediments and radiance or reflectance calculated from raw pixel data or dark pixel corrected data, suggesting that the dark pixel correction was not effective in improving the relationship for this data set. Ritchie et al. (1987) obtained improved correlation coefficients for the relationship between suspended sediments and radiance when similar dark pixel corrected MSS data were used in an earlier 3-year study on Moon Lake.

The highest correlations were between suspended sediments and reflectance in MSS Band 3 (0.7–0.8 μm) (Fig. 1), MSS Band 4 (0.8–1.1 μm) (Figs. 2 and 3), and TM Band 4 (0.76–0.90 μm) (Fig. 4). These are the regions of the spectrum that have been shown to provide the highest correlations between Landsat data and suspended sediments in other studies (Carpenter and Carpenter, 1983; Harrington et al., 1989; Lathrop and Lillesand, 1986; Lindell et al., 1986; Lyons et al., 1988; Ritchie et al., 1987, 1989; Ritchie and Cooper, 1988; Schiebe et al., 1988; Verdin, 1985). The regression models fitted to the suspended sediments and spectral data from these three bands accounted for 73–77% of the variability in the data.

There were no significant differences in the models for suspended sediments using TM data over those using MSS data when using the best models for each. Concentration of suspended sediments was equally related to either MSS or TM data. Therefore, the improved spectral resolution of TM data (narrower band width) did not provide any better relationships with surface suspended sediments. Thus, the major justification for using TM data to monitor surface suspended sediments would be its higher spatial resolution that would allow monitoring smaller lakes. Such small lakes and reservoirs play an important role in agricultural landscapes (Dendy et al., 1978) and data on surface water quality in small agricultural lakes would be valuable in developing conservation assessments and plans for individual farms. However, before choosing MSS or TM data, one must consider the increased volume of TM data (approximately seven times more) needed to cover the same area. Therefore, in developing a monitoring program using Landsat sensors, it is necessary to define the minimum size lake to be monitored before choosing to use either MSS or TM. This study indicated that either sensor could be used to determine suspended sediments.

The highest correlation for either chlorophyll-a or total chlorophyll was with reflectance (Table 6) measured by TM Band 1 (0.42–0.52 μm) (Fig. 5). As with suspended sediments, a linear model provided the best fit with this data set. Different band combinations and ratios did not provide improved correlations with chlorphyll over TM Band 1 reflectance. The regression model accounted for 47% (total chlorophyll) or 53% (chlorophyll-a) of the variation in the data, but they were the only models that would account for a majority of the variability in the data. For chlorophyll, the broad spectral bands measured by the MSS sensor have not proven to be highly correlated to chlorophyll in agricultural lakes and reservoirs where the reflected solar radiation is most often dominated by the reflectance from suspended sediments (Ritchie et al., 1986). This is evident in the correlation coefficients between MSS data and chlorophyll

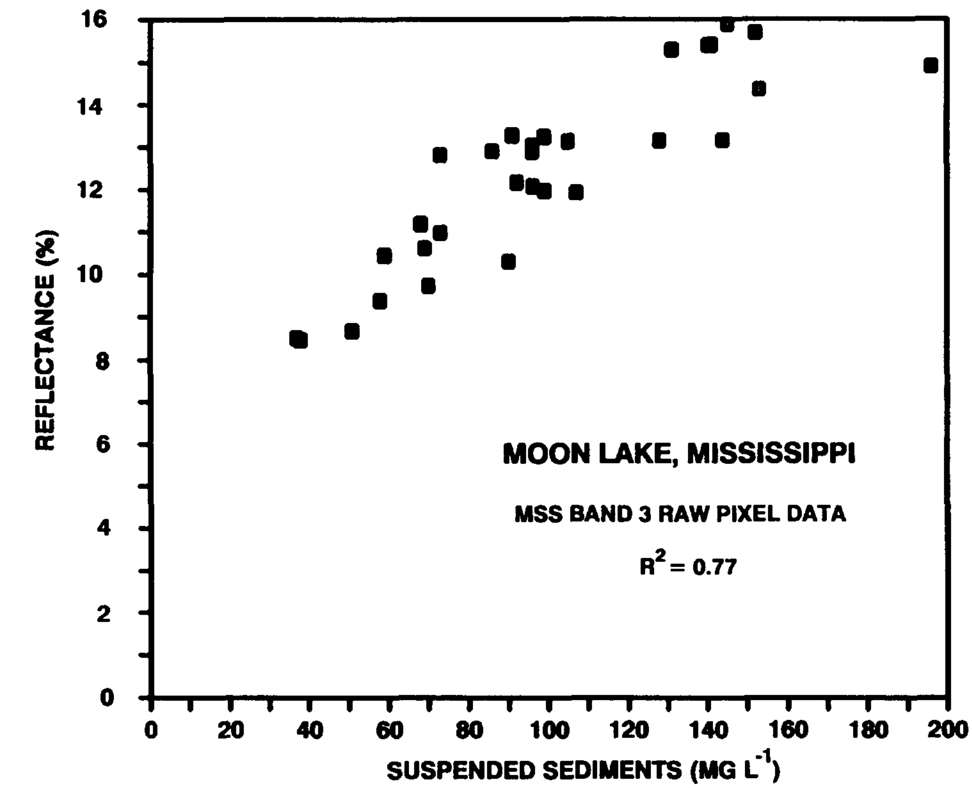

Figure 1. Relationship between MSS Band 3 reflectance data calculated from raw pixel data and suspended sediments.

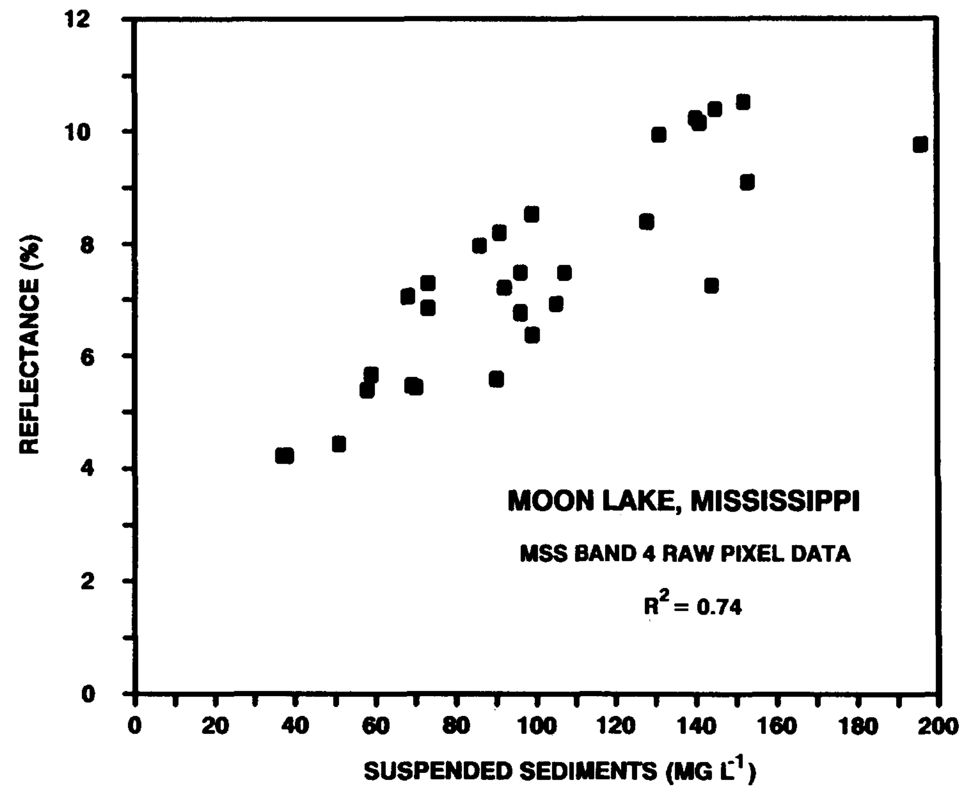

Figure 2. Relationship between MSS Band 4 reflectance data calculated from raw pixel data and suspended sediments.

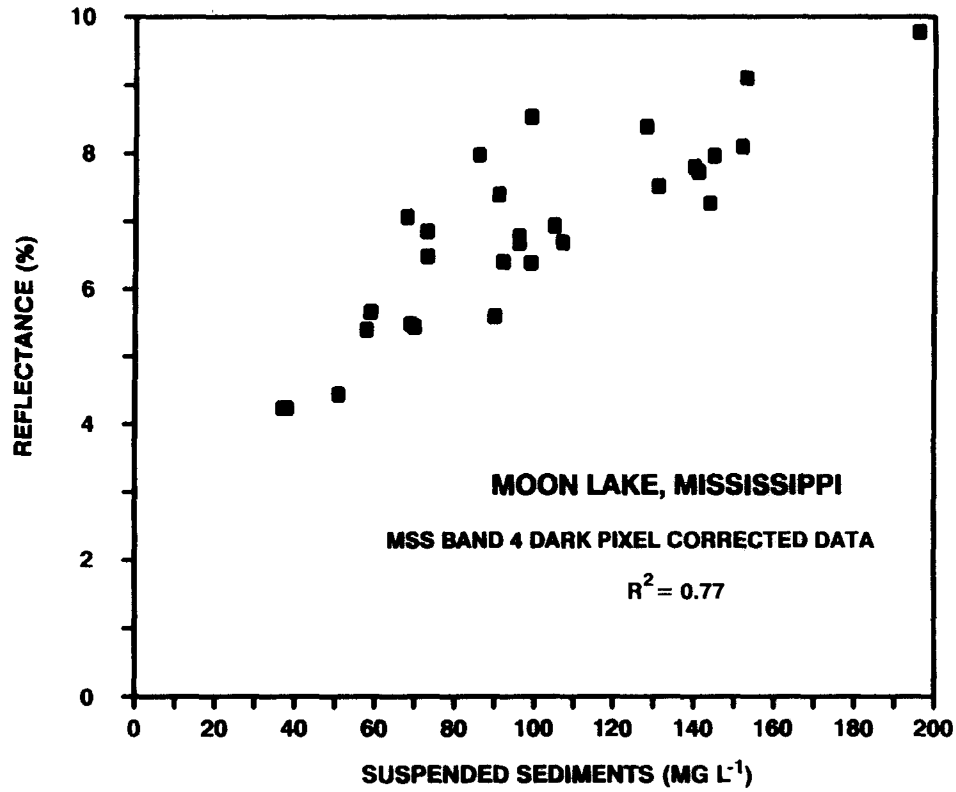

Figure 3. Relationship between MSS Band 4 reflectance data calculated from dark pixel corrected pixel data data and suspended sediments.

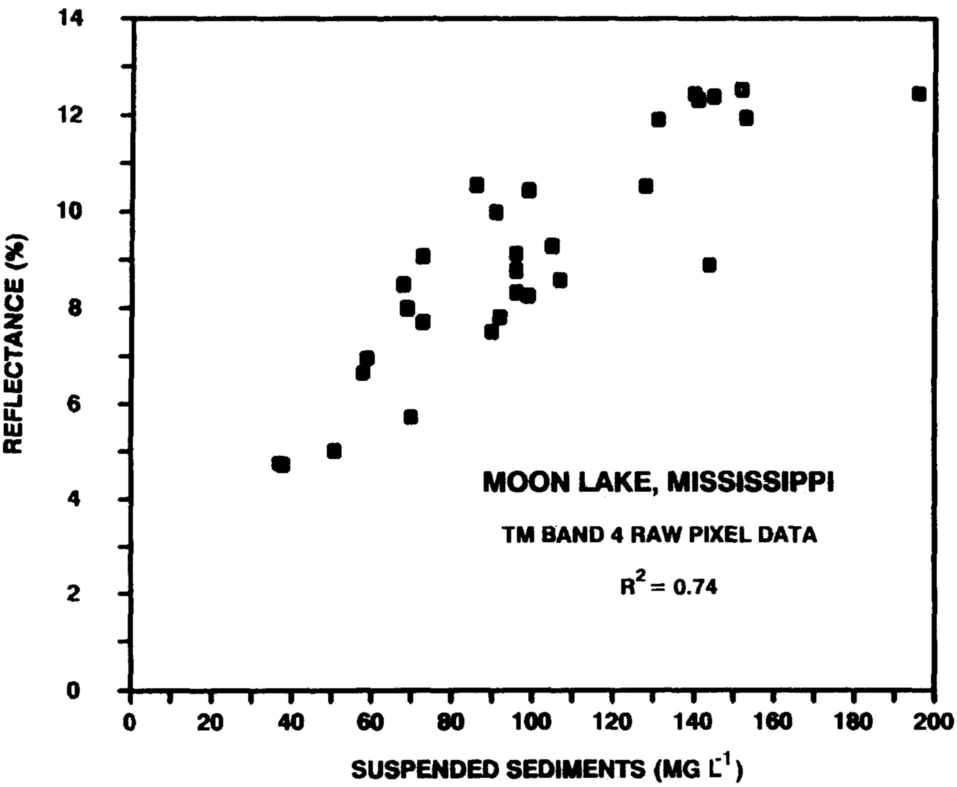

Figure 4. Relationship between TM Band 4 reflectance data calculated from raw pixel data and suspended sediments.

Table 6. Correlation Coefficients (*r*) for a Linear Relationship between Chlorophyll and Radiance or Reflectance Calculated from Landsat MSS and TM Sensor Data

	Band 1	*Band 2*	*Band 3*	*Band 4*
	Total Chlorophyll			
	Calculated from Raw Pixel Data			
MSS radiance	0.33	0.35	0.26	0.11
MSS reflectance	−0.13	0.06	−0.01	−0.16
TM radiance	0.28	0.34	0.33	0.20
TM reflectance	−0.69	−0.40	−0.26	−0.07
	Calculated from Dark Pixel Corrected Data			
MSS radiance	0.42	0.43	0.51	0.28
MSS reflectance	−0.20	0.19	0.21	−0.05
TM radiance	0.37	0.43	0.49	0.54
TM reflectance	−0.02	−0.21	0.29	0.23
	Chlorophyll-a			
	Calculated from Raw Pixel Data			
MSS radiance	0.33	0.34	0.24	0.09
MSS reflectance	−0.14	0.02	−0.07	−0.23
TM radiance	0.28	0.34	0.31	0.18
TM reflectance	−0.73	−0.45	−0.33	−0.15
	Calculated from Dark Pixel Corrected Data			
MSS radiance	0.37	0.43	0.50	0.25
MSS reflectance	−0.27	0.16	0.16	−0.15
TM radiance	0.37	0.40	0.50	0.51
TM reflectance	−0.06	−0.28	0.26	0.15

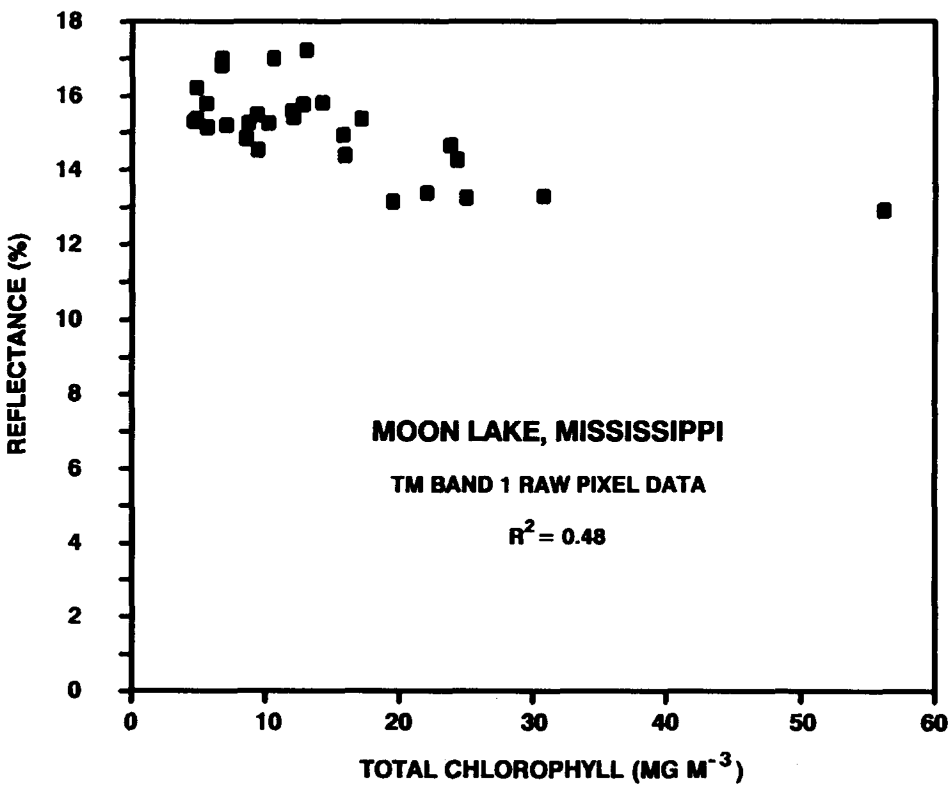

Figure 5. Relationship between TM Band 1 reflectance data calculated from raw pixel data and total chlorophyll.

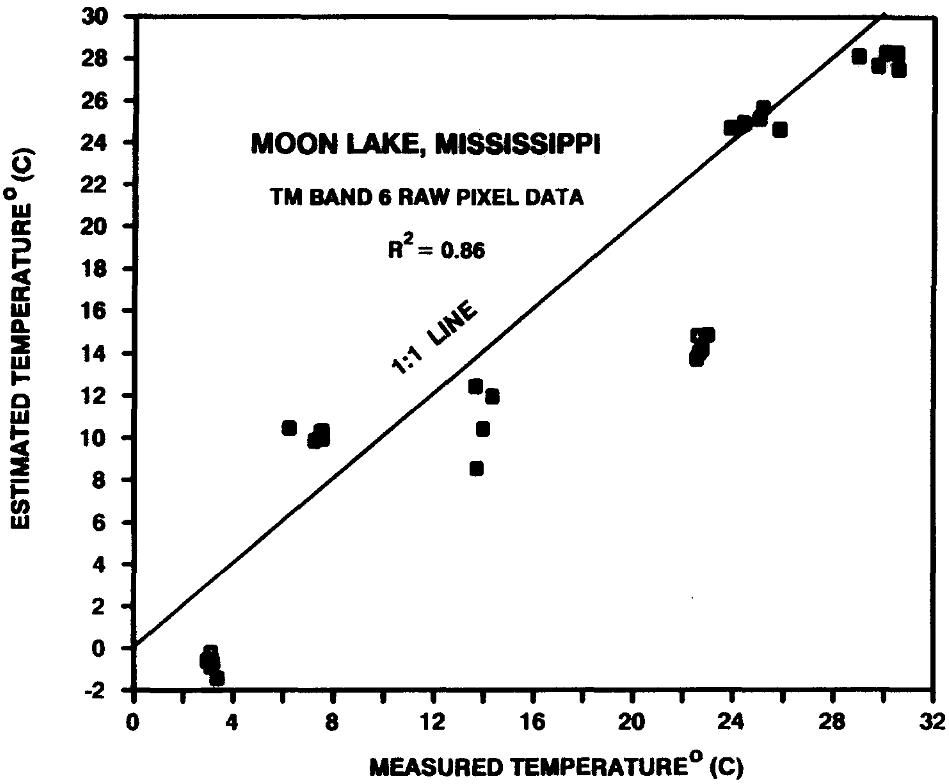

Figure 6. Relationship between surface water temperatures estimated from TM Band 6 data and measured temperatures.

(Table 6) for the Moon Lake data set used in this study. TM with narrower bands, especially Band 1, in a region of chlorophyll absorption offers some promise for estimating chlorophyll. However, correlations between chlorophyll and TM Band 1 data in lakes like Moon Lake, where the radiance and reflectance measurements are dominated by reflectance from suspended sediments, probably will not be adequate for monitoring changes in the surface waters due to chlorophyll. Narrower bands, such as those proposed for High-Resolution Imaging Spectrometer (HIRIS) or Moderate-Resolution Imaging Spectrometer (MODIS) instruments on the Earth Observing System (EOS) (NASA, 1988), may provide better data for determining chlorophyll in the surface water of sediment dominated lakes and reservoirs.

Thermal band from TM Band 6 (10.5–12.5 μm) was accurate to within 1–2°C for measuring surface water temperatures (Gibbons et al., 1989; Lansing and Barker, 1984; Wukelic et al., 1985). Estimates of surface water temperature in Moon Lake were made using the equation provided by Markham and Barker (1986). These equations provide temperature estimates that are not corrected for atmospheric changes due to water vapor or ozone.

The temperature of the surface water in Moon Lake estimated with TM Band 6 data are highly related to the surface water temperatures measured in the field (Fig. 6). On four of the six dates, satellite-estimated temperature and field-measured temperatures fell within 3°C of each other. On another date (January 26, 1985) the difference averaged 3.9°C. On that date of the satellite overpass, part of the surface of the lake was frozen, which is indicated by the satellite estimated temperatures. The field temperature used for comparison was measured 18 days later. During this 18-day period, the maximum air temperature averaged 3°C that is nearly the same as the measured surface water temperature (3.16°C). On the other date (18 May 1985), the satellite estimated temperature was 8°C cooler than the field measured temperature. Although the average minimum and maximum air temperatures between the date of the field measurement (16 May 1985) and the satellite overpass (18 May 1985) were 4°C cooler, there was no precipitation or other known factor that would have caused an 8°C difference in temperature. This may be an example where atmospheric transmission affected the radiance measured by the TM thermal band. These estimates of surface water temperature show the potential of using TM thermal data to measure water temperature.

CONCLUSION

From this study of six concurrent Landsat MSS and TM scenes, there are no significant differences in the correlation between surface suspended sediments and either MSS or TM data for the best fits with a linear model. The advantage of using MSS data would be the ability to monitor large areas with significantly less data. The advantage of TM data would be the ability to monitor smaller lakes and reservoirs. Thus, in selecting the Landsat sensor to use in monitoring surface suspended sediments, one must consider the minimum size lake or reservoir that needs to be monitored.

TM Band 1 data provided the only regression relationship that accounted for at least 50% of the variability in the chlorophyll data. Such a relationship is not adequate for a monitoring program for chlorophyll. In sediment dominated lakes, such as Moon Lake, development of a satellite monitoring system for chlorophyll probably will have to wait for data from new sensors that can provide higher spectral resolution around chlorophyll absorption and reflectance peaks. With higher resolution spectral data it may be possible to separate the reflectance from chlorophyll and suspended sediments.

TM thermal data from Band 6 allows accurate estimates of surface water temperature to be made. Such estimates could be useful in estimating the water balance in small agricultural watersheds.

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